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Sojourner Mars Rover Thermal Performance

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ABSTRACT

The Sojourner Rover landed on the surface of Mars on July 4, 1997 as part of the Mars Pathfinder Mission. The mission lasted almost three months during which the thermal design of the Rover was tested. This paper summarizes the Rover's design and performance as well as post-mission model correlation.

INTRODUCTION

The Mars Pathfinder Sojourner Rover configuration, from a thermal perspective, was dominated by a flat top solar array, a WEB (Warm Electronics Box), six-driving wheels with four steering actuators. Three RHU (Radioisotope Heater Units) were employed as a constant heat source. Thermal insulation panels (WEB walls) were constructed using solid SiO_2 aerogel as lining of the fiberglass epoxy sheet-and-spar box[1,2}.

Sojourner's design was a result of its driving requirements:

1. A 7-day Sojourner nominal mission meant there were no temperature excursions due to seasonal changes. Dust accumulation, property degradations and thermal cycling wear-outs were not major considerations.
2. Sojourner carried only one single major science instrument – APXS as well as some external engineering systems (motors, cameras, etc). Penetrations of the walls of the WEB were minimized.
3. The major thermal requirement for Sojourner is for the primary battery pack, which was set to be -40°C to +55°C each day with no more than 5 hours above +40°C.

The thermal performance of a Rover on the surface of Mars was governed by three groups of parameters: (1) Environmental conditions, including temperatures, insolation and wind conditions; (2) internal power dissipations associated with operational sequences; and (3) thermal design features.

Thermal performance during the first few days after the Pathfinder landing will be reviewed in this paper. Actual mission temperature data are compared with the pre-flight predictions. A post-flight thermal model was reconstructed to correlate with the measurements. The model correction process can reveal weakness involved in the Sojourner thermal design approach, both in technical understanding and the associated test programs.

SOJOURNER CONSTRUCTION AND COMPONENTS

The total mobile mass for the Mars Pathfinder Microrover Flight Experiment mobile vehicle, Sojourner, was 10.6 kg. Figure 1 shows a photogaph of the Rover exterior in stand-up mode which moving around the Martian surface. The Rover coordinate system is defined as follows: The +X axis points forward (to the right in the photo); the +Z axis points Nadir downward and the +Y completes a right hand Cartesian set (Starboard). The basic Warm Electronic Box (WEB) is contained within a volume of 340 mm long by 275 mm wide by 150 mm tall. The Alpha-Proton X-ray Spectrometer (APXS) scientific instrument is located at the -X end of the Rover, exterior to the WEB. The Rover is equipped with three exterior imaging/navigation CCD cameras, one aft and two forwards. Sojourner maintained a two-way communication with the Mars Pathfinder Lander via an ultra-high frequency (UHF) link and a pair of commercial RF modems, one inside the WEB and the other mounted to the Lander Battery inside the Lander's thermal enclosure. Rover mobility was provided by a six-wheel drive, rocker-bogie suspension system developed in the early 1990's at JPL. A cable tunnel located at the +X end of the Rover increased the path length (and thus minimized conductive losses) for all electrical cabling which penetrating the WEB walls. This cabling was used to connect the interior components with the solar array, motor actuators, cameras, APXS, and other external devices.

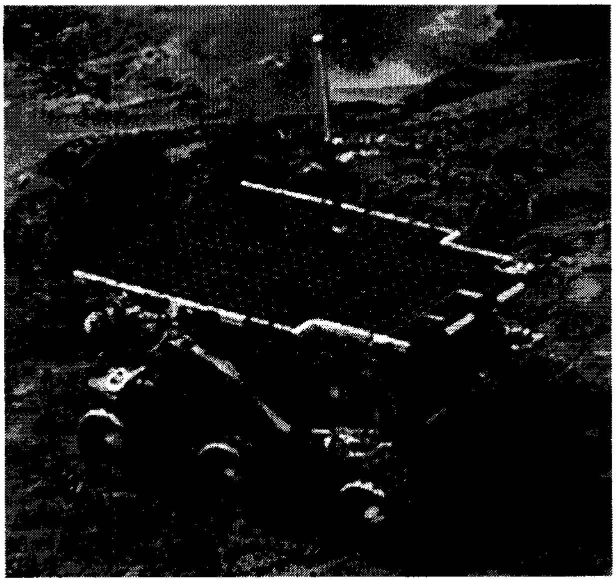


Figure 1 - Sojourner Rover on Mars

For the landed operations, a solar panel and primary batteries supplied Rover power. The Rover solar panel surface area of approximately 2200 cm^2 was composed of 13 diode-isolated strings of 18 GaAs/Ge cells, 5.5 mil thick, 2x4 cm per cell, with 3-mil cover glasses. Peak power was 15.3 W maximum at noontime at approximately 15.5 V. The NASA/LeRC-provided MAE (Materials Adherence technology Experiment) was located at the -Y/+X corner of the solar panel. The remaining part of the power subsystem consisted of three strings of lithium-thionyl chloride primary (non-rechargeable) battery cells and various DC/DC converters, switching regulators, and inverters to provide necessary voltage levels. The lithium battery pack was designed to provide approximately 150 W-hrs of energy at 50% depth of discharge. The batteries were entirely consumed during the mission by nighttime science and engineering measurements.

SOJOURNER THERMAL DESIGN AND VERIFICATION PROCESS

The temperature control activities for Sojourner, on a chronological basis, can be separated in three sequential but overlapping processes: (1) the design trade-off and parametric study; (2) component developmental testing; and (3) subsystem thermal validation testing. The strategy for Rover temperature control is rather unique and in many aspects deviates significantly from typical JPL practices, including that of the Pathfinder Spacecraft. First of all, because of the severe constraints on weight and volume limitations and its Class-D flight classification requirement, minimal design margins (basically zero) were considered between the designed thermal performance and the Allowable Flight Temperature limits (AFT). The only margins which existed were between the AFT and the qualification temperature of the hardware, typically 10 to 15 degrees C. Secondly, many transient mission environmental conditions can not be accurately reproduced inside the test chamber, approximations and analytical extrapolations were implemented. In order to minimize the risk associated with the slim design margins and the large environmental uncertainties, the MTM (Mechanical, Thermal & Mobility Subsystem) management directed the thermal control approach to concentrate on the WEB development and temperature control of interior components. Very extensive developmental thermal tests were conducted and the Rover thermal model was continuously upgraded to assure that interior thermal requirements could be satisfied.

On the other hand, after an aggressive early phase activity, the thermal follow-up tasks for Sojourner were less rigorous. There was a strong contrast between the thermal validation philosophy between the Pathfinder and Sojourner management. The Mars Pathfinder Lander had practically no thermal development test but had an extensive thermal balance test and a system level STV (Solar-Thermal-Vacuum) test. The Lander thermal model was correlated with the STV test results and the resultant model was used for mission operation. Thermal support for the Mars Pathfinder Fight System mission operation was very active. The pre-flight thermal model was correlated with down-loaded flight temperatures on a daily basis. Projection of the Lander component temperatures were made according to power profiles generated by the systems engineer and environmental temperatures (typically that of the previous day). The process was demonstrated to be effective to provide realistic flight temperature projections.

Although the Rover did participate the Pathfinder system-level STV test for functional check-out, there was no thermal testing nor any attempt to correlate the Rover thermal model prediction under the STV environment. Sojourner thermal activity was terminated months before the beginning of the STV test. The pre-flight Rover thermal model was not used actively during the mission operation period. The Rover operations team used some pre-flight-predictions and trending of flight data as the source of its thermal decisions. This also proved to be mostly effective in managing the thermal performance of the Rover.

When the Sojourner thermal flight data was reviewed post-mission, there were some surprises. Although most of these discrepancies are on peripheral components and would not have jeopardized the Sojourner mission in any fashion, nevertheless most of these discrepancies could have been corrected if STV activities were augmented to include more fidelity and analysis

SOJOURNER THERMAL PERFORMANCE

Nominal design atmospheric temperature profile for Pathfinder mission was referenced to the average measured temperature profile (at 1.6 m above ground) from Viking Lander 1 (VL1 at 22.3°N latitude), shown in Figure 2 [3,4]. There were thirteen PRTs (Platinum Resistor Thermometer) on Sojourner as flight temperature sensors. Seven of them were for monitoring interior component temperatures: three on the primary battery strings; one on the WEB interior wall (+X end); one each on the modem, the CPU and the power board. The six external PRTs were on the port forward drive motor, the starboard forward drive motor, the MAE and the three cameras. In the following paragraphs, the flight temperature data are discussed and compared with the corresponding post-flight thermal analysis and modeling. The selected set for comparison is from Sol-4 to Sol-6 (A sol is a Martian solar day). Sol-1 is referenced to the Pathfinder Landing on 3 AM LST (Local Solar Time), July 4, 1997.

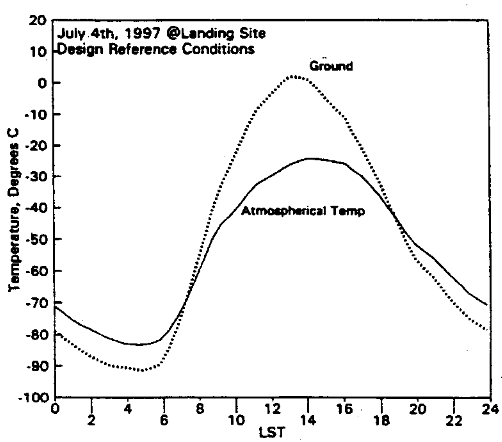


Figure 2: Design atmospheric and ground diurnal temperatures.

Rover thermal performance can be categorized into three groups: (a) the solar array; (b) the peripheral components; and (c) the interior components. The solar array is relatively isolated from the rest of the system and its thermal behavior receives little influence from the rest of the Rover or the ground radiation. The peripheral components, i.e., the cameras, the Rocker-Bogies and the actuators, are basically exposed and are strongly affected by the environmental interaction. The WEB insulation characteristics and internal power dissipation, on the other hand, dictate the temperatures of the interior components.

SOLAR ARRAY

The Sojourner solar panel was divided into two regions; the center (over the WEB) and the rim area that overhung the Rover body. The central portion has an area of 894 cm^2 and is mounted on the thick aerogel insulation lid of the WEB. The rim parts have thinner panel thickness and their back surfaces are exposed to the environment. A flight temperature sensor is mounted on the +X sector of the solar panel near the MAE. Solar panel power generation is computed based on a subroutine provided by R. Ewell/JPL, assuming a reference cell efficiency of 18.2% and a packing density of 87%. Maximum power output is calculated using the central sector cell temperature. The reference design environment is specified in the following:

Ls = 143° = aerocentric longitude (0 is Northern Hemisphere vernal equinox)

Phi = 19.5° = Lander latitude

Mask = 0° = terrain mask

Albedo = 0.2 = Mars surface albedo factor

Tau = O.2

Air/Ground temperatures (see Figure 2 reference)

Wind condition: Low (< 2 m/s)

Sky Radiation: 62 K to 70 K

Surface Atmospheric Pressure (8 torr)

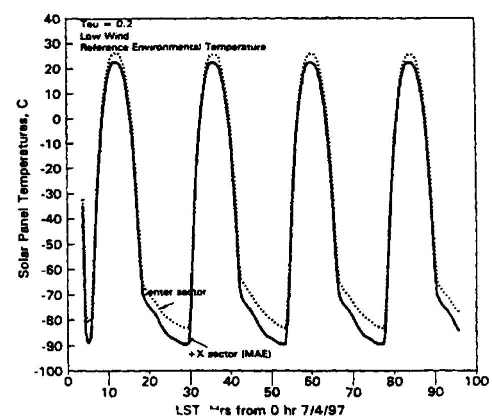


Figure 3a - Pre-Flight Temperature Predictions for Solar Panel.

Figure 3a [taken from Ref. 5] shows the pre-flight solar panel temperature predictions for the reference design condition. Solar panel temperatures are computed assuming an effective solar absorptance of 0.816 and a surface emittance of 0.78. The center sector of the solar panel is approximately 5 to 10 degrees C warmer than the rim sector, where MAE is located. The power generated by the Rover solar panel is considered extracted and dissipated elsewhere. In comparison to the

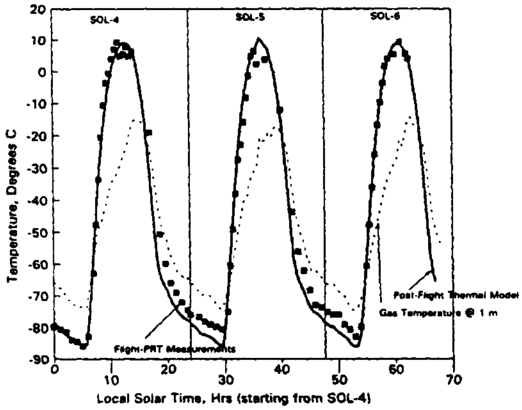


Figure 3b - Post-Flight Temperature Model for Solar Panel.

flight PRT measurement shown in Figure 3b, the pre-flight prediction (for MAE) is approximately 10°C too hot for the daytime maximum (20°C vs. 10°C) and 5- to 10-deg C too cold for the pre-dawn minimum (-90°C vs. -80 to -85°C).

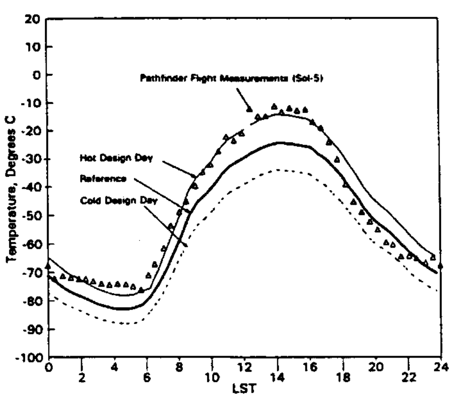


Figure 4: Comparison of Sojourner design air temperatures with actual data.

The Pathfinder flight-measured air-temperature profile turned out to be very close to the design limits, where a range of ~5-deg C on the low side and ~10-deg C on the high side were added to the reference profile to be the nominal hot and cold design days[4]. Figure 4 compares the design conditions of the hot, reference and cold profiles with the actual ASI/MET measurements (at 1 m above ground) on Sol-5 (July 9th, 1997) at the Pathfinder landing site of 19.5 N. The actual air temperature between 0:00 and 16:00 (LST) matches the hot-day design profile, while the reference profile was a good representation for the evening. It is obvious that the difference in environmental air temperature does not contribute to the discrepancy between pre-flight predictions and flight data (it would have made the daytime prediction even higher and not raising the night time level). The environmental parameters that can make a difference (and thus need to be adjusted) would have to be wind speed (forced convection) and sky radiation.

Sky Radiation

Sky radiation is often expressed in terms of an equivalent blackbody temperature, T_{sky}, to characterize the downward IR radiation, using the emissive power relationship $q_{IR} = \sigma T^4_{sky}$, where σ is the Stefan-Boltzmann constant (5.669E-8 W/m^2-K^4) and T_{sky} in Kelvin.

The sky temperature for Pathfinder Lander design was adopted with a very conservative space radiation condition of 4K. The sky radiation design condition for Sojourner was 70 K [4]. An effective blackbody sky temperature of 140 K was suggested for Pathfinder mission operation temperature control. This assumption was somewhat validated by the analysis of measured nighttime petal temperatures. The recommended sky radiation for future rovers is shown in Figure 5, which displays an effective sky temperature of 135 K for Pathfinder night temperature of 200 K (-73°C).

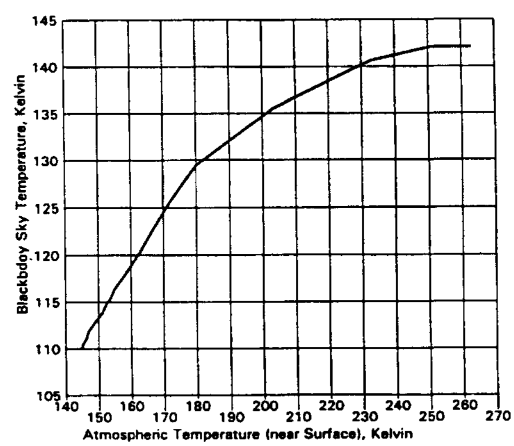


Figure 5: Blackbody sky temperature verses Martian air temperature.

(ii) Surface Wind

Forced convection on the surface of Mars is a significant heat transfer mode for Rover operations. Although the Pathfinder Lander carried a weather station (ASI/MET) to measure wind velocity at the landing site, no quantitative data were reported to the mission operation team throughout the mission. According to T. Schofield [6] the Pathfinder site was rather calm during the mission period and the effective free stream wind speed was no more than 10 m/s.

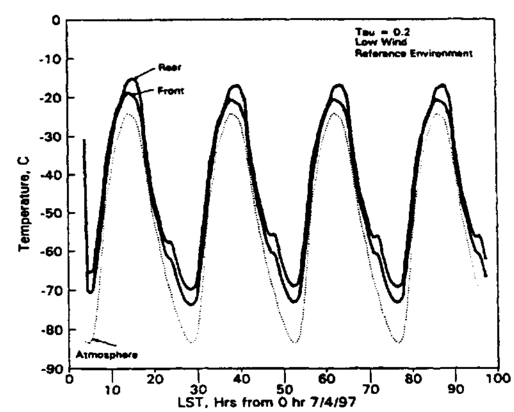
The first step of post-flight thermal model adjustment consists of the incorporation of the new sky temperature correlation (as shown in Figure 5) and the assumption of a constant free-stream wind speed of 10 m/s. As can be seen from Figure -3-b, the post-flight adjustments were able to reduce the analysis/measurement discrepancies for the solar array to an acceptable level.

PERIPHERAL COMPONENTS

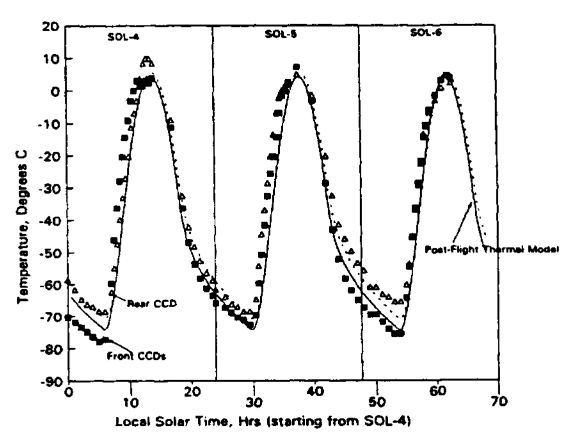
Sojourner peripheral components include the APXS assembly, the drive and steering mechanisms, the rocker-bogie and the CCD camera & laser housing. Because they were situated outside the WEB, the temperature behaviors are essentially driven by the environmental conditions. Figures 6-a and 7-a [taken from Ref. 5] show the pre-flight temperature predictions for the CCD camera and the drive actuators. The temperatures of peripheral components are anticipated to be 5 to 10°C warmer than the environmental air temperature. The actual flight data for the CCDs and the Drives in Sol-4 to Sol-6 are shown in Figures 6-b and 7-b respectively. The daytime peripheral temperatures are surprisingly close to that of the solar array and are much warmer than the pre-flight predictions. This was not anticipated. First of all, the CCDs are underneath the solar array and do not have direct solar flux impingement. Secondly, the Sojourner thermal model had been verified through a number of developmental tests before the pre-flight predictions were made. Figures 8-a and 8-b compare the test results and predictions of the peripheral components during the MTM testing [7] in June 1995. Figures 9-a and 9-b validates the pre-flight model with test data in the Rover SIM QUAL test [8], where solar irradiation was simulated with IR radiators. In both cases the analytical predictions were demonstrated to be within 5°C of test measurements.

The good correlation between model predictions and the results of developmental tests was translated into a high level of confidence with small prediction margins. This contributed to early termination of Rover thermal analysis support and the decision not to perform thermal correlation in the Lander System Level Solar Thermal Vacuum (STV-2) test, in which the Rover participated for functional operation only. Furthermore, the imperfections of the STV test (no moving solar illumination, Nitrogen instead of CO_2 environment) and its primary goal, Lander margin validation, put the tests value to the Rover design in question. In retrospect, it is recognized that It may not have been prudent to substitute the expensive STV testing with cheaper developmental testing, even after a very extensive developmental testing program such as that for the Sojourner. It was stated earlier that the thermal performance of a Rover is governed by three groups of parameters, namely, the Rover thermal characteristics, the environmental interaction and power dissipations. Only the thermal characteristics can be fined-tuned in developmental tests. In most cases, the thermal interactions among the Rover components and solar radiation fluxes which was approximated in earlier tests (without Solar spectral illumination) can only be validated in a system level STV test. However, it also should be noted that Rover operational sequences and thus heat dissipation profiles changed greatly during the Rover development and were not consistent between Rover Qualification testing, STV, and then flight.

In lieu of the STV test correlation, flight data has been used to assist the adjustment of the pre-flight model to create a post-flight thermal model. Several environmental interaction parameters were tweaked to obtain a better correlation with the flight measurements. Two of these parameters have already been discussed above (in the process of correlating solar array temperatures), i.e. (i) sky radiation and (ii) free stream wind speed. Four additional parameters are also being adjusted to correlate the CCD and Drive actuator flight data.

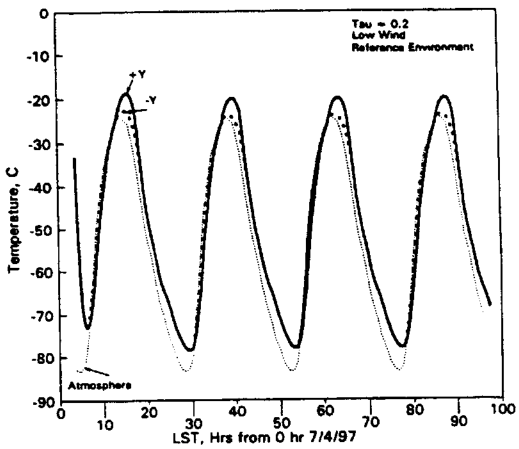


(a)

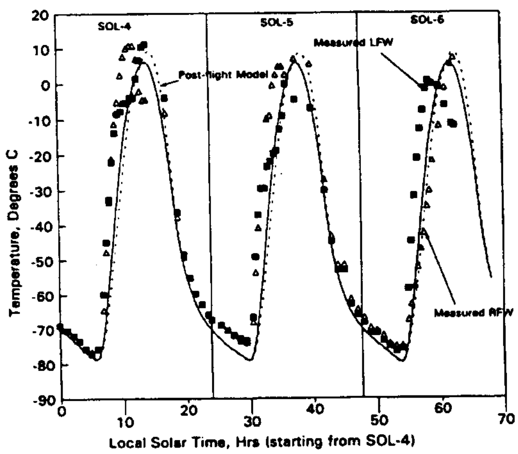


(b)

Figure 6: (a) Preflight prediction and (b) Postflight actual CCD camera temperature profiles.



(a)



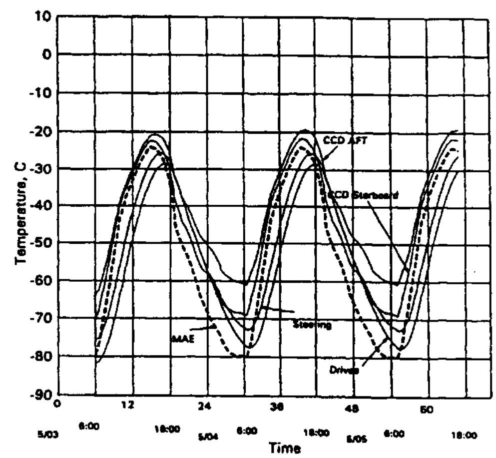
(b)

Figure 7: (a) Preflight prediction and (b) Postflight actual drive actuator temperature profiles

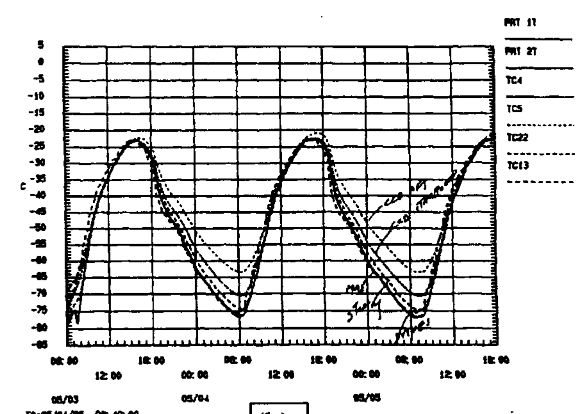
They are discussed in the following sections: ground thermal emission; ground reflection of solar flux; sub-layer wind and sublayer air temperature. Because of the low level of component power dissipation and its intermittent nature, heat dissipations in the CCDs and the actuators were ignored in the models.

Ground Thermal Emission

For the Pathfinder project, the reference ground temperature profile was provided along with the reference air temperature profile as shown in Figure 2. It can be seen that for clear days the Mars ground temperature is significantly higher than the corresponding air temperature during sunlit hours because of the absorption of solar flux. At night, the ground temperature is approximately 10°C lower than corresponding air temperature because of sky radiation. There was no ground temperature measurement for the Pathfinder mission, but the thermal interactions among the ground and the gas layers can be adequately modeled. It is possible to assess the ground temperature behavior based on the insolation algorithm (location and areocentric longitude) and free stream air temperature.



(a)



(b)

Figure 8: (a) Preflight prediction and (b) system thermal vacuum peripheral component temperature profiles.

For the Sojourner post-flight thermal model, two regions of ground nodal zones were simulated, an exposed ground zone and a underspace ground zone. A 10-layer thermal network model represented each zone. The exposed ground zone receives unobstructed solar irradiation (with an albedo around 0.3 to match the temperature profile shown in Figure 2) and has a full view of the sky. The underspace ground zone represents the ground layers underneath the Rover. Its behavior would be identical to the exposed ground zone as long as the Rover is moving. In the evening, when the Rover is resting, the underspace ground has a full view of the Rover's belly pan (instead of the cold sky) and the cool-off rate is much slower than that of the exposed ground. The view factors from most peripheral components to the exposed ground (including reflections from the back surface of the solar array rims), are typically around 1/2 to 2/3. Only the belly pan on the underside of the WEB has 100% view factor to the underspace ground.

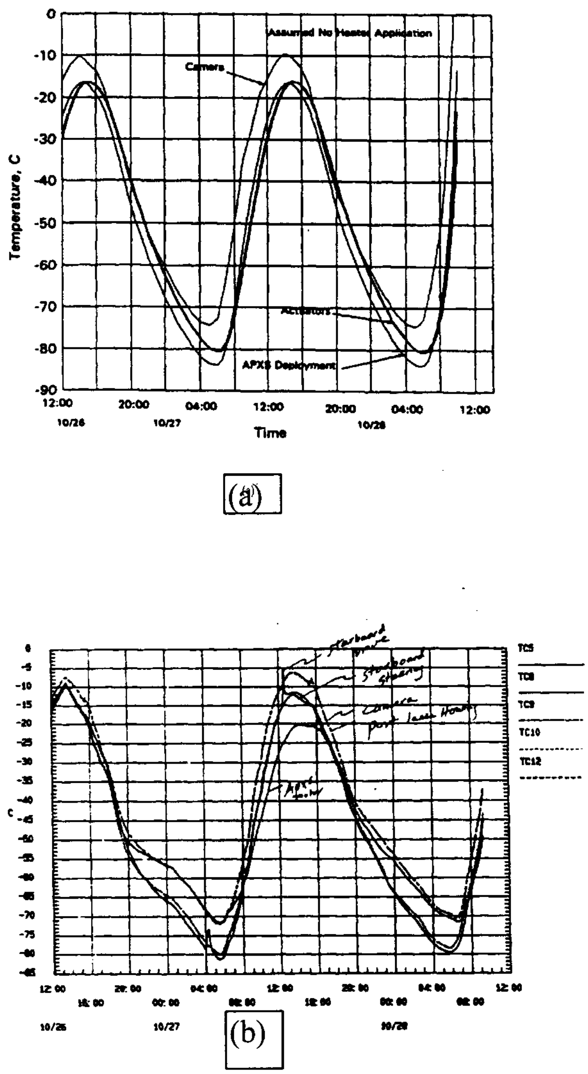


Figure 9: (a) Preflight prediction (a) and (b) system thermal vacuum peripheral component temperature profiles with simulated solar irradiation.

Ground Reflection of Solar Flux

Reflection of solar flux from the ground to the peripheral components was not accounted for in the pre-flight model. The effective reflected solar flux impingement (from the ground) to the CCD cameras would be 20% of the insolation (solar flux to the ground) based on the reciprocity relationship of the view factors.

Sublayer Wind Speed

Drag forces at the ground surface influence wind speed. The vertical variation of wind speed is strongly affected by terrain roughness until the height reaches the "gradient height". Because of the low air density on Mars, the air boundary layer thickness is considered to be of the order of 1 meter. The effective wind speed around the Rover is estimated to be less than half of the free stream wind speed measured on the ASI/MET instrument mast. The effective wind underneath the solar array should be no more than 20% of the free stream values. Structural blockage of the wind would be another factor. The wind condition at the CCD would be severely blocked by the WEB, the solar array and the cable tunnel. The effective wind speed is estimated at less than 50% of the corresponding unblocked value.

Sublayer Air Temperature

Because of the thick boundary layer above ground and the differences in effective wind speed in different air layers the temperature gradient can be noticeable. In the post-flight thermal model the convection between the Rover and surrounding atmosphere were divided into five zones: three zones for the open regions (with unblocked wind) and two zones around the Rover. Figure 10 compares simulated temperatures of the ground and the sublayers with the ASI/MET data on SOL-5 of Pathfinder mission measured at three different heights: at 1 m, 0.5 m, and 0.25 m.

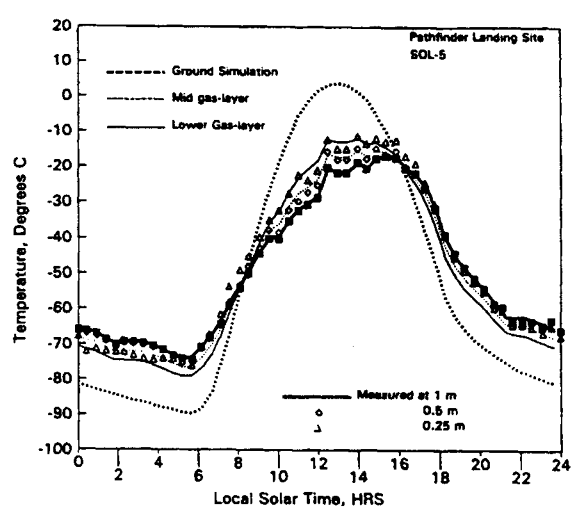
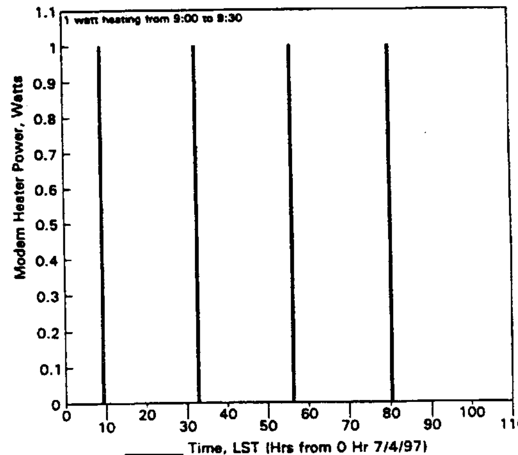


Figure 10: Simulated ground and sublayer air temperatures.

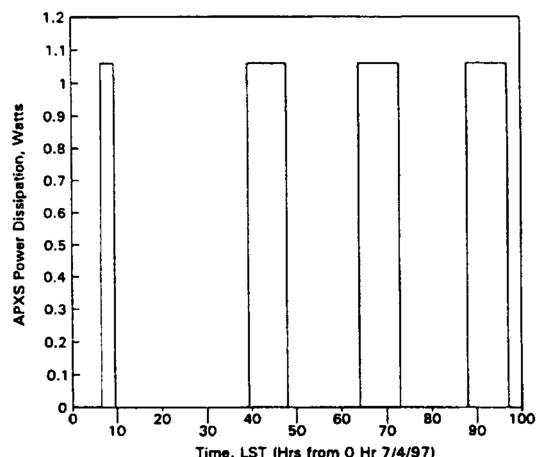
The parameter adjustments discussed in these 6 areas enabled the post-flight model to achieve a reasonably close correlation with the measured flight data as shown in Figures 6-b and 7-b.

INTERNAL COMPONENTS

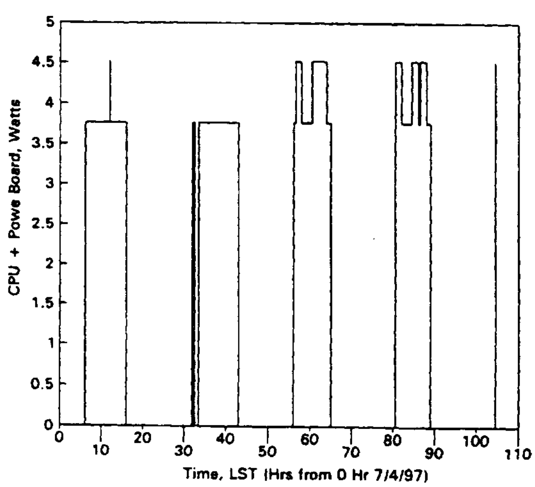
Components inside the Sojourner Warn Electronic Box (WEB) were to be kept within a temperature range of +40°C to -40°C. The batteries were allowed to rise up to +50°C for a limited time each day. The WEB is insulated with aerogel panels such that the interior is not very sensitive to environmental changes. The three RHU's were installed inside the "Jeff-tube" to provide a constant power source of 2.925 watts. In additional to the constant RHU heat supply, thermal dissipation due to equipment operation strongly affects the temperature variations inside the WEB. Figures 11a, 11b, and 11c show the nominal pre-flight assessments of power profiles for the electronic packages (the CPU board and the power board), the modem heating and the APXS power schedule respectively. Figures 12-a,b, and c show the comparisons between the recorded flight temperature data and those predicted by the post-flight thermal model. It is noted that, no additional adjustments, other than the six areas mentioned earlier, were applied. The correlation shows a certain degree of time lag of the predicted temperature profile as compared with the measured data. The differences between the assumed power profiles (as specified in Figure 11) and the actual power dissipation could cause this. It is also noted that as far as the interior components are concerned the post-flight model does not show any improvement as compared with the pre-flight model.



(b) Modem Heater Operating Schedule



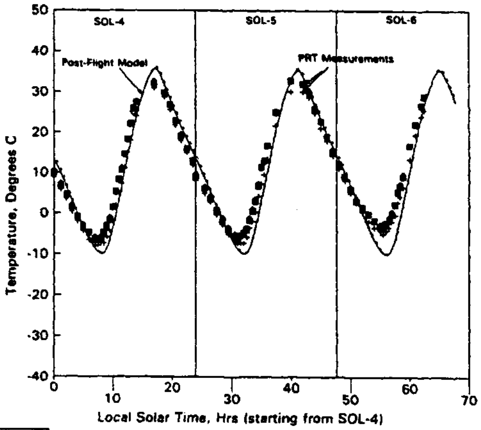
(C APXS Power Dissipation Schedule



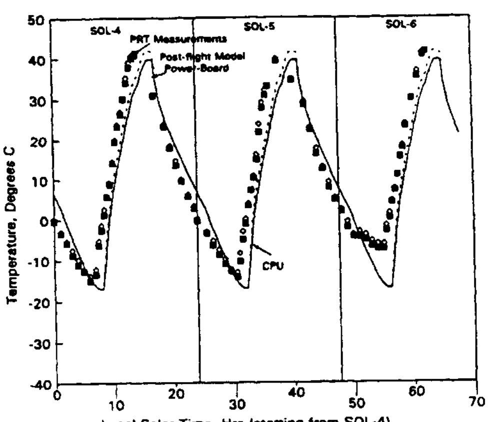
(a) Rover Interior Dissipation from CPU and Power Board

Figure 11: Rover (a) nternal power, (b) modem heater cycle, and (c) APXS power dissapation cycle.

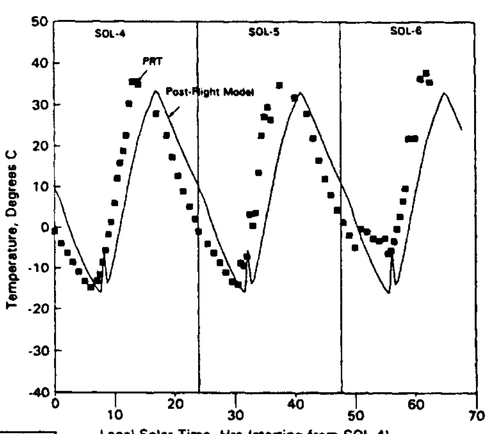
It should be recalled that the interior components were all the electronics that controlled the Rover operations and were most sensitive to temperature. The interior electronics were fabricated from standard aerospace or commercial components and techniques and thus needed to be controlled to MIL-SPEC temperatures (+40°C to -40°C). The pre-flight temperature predictions [5] include variations for a reference day, a hot day, a cold day, a dusty day and a dust storm day. As can be seen from Figure 4 the measured air temperature profile was very close to the hot day profile, except a few hours in the evening (from 18th to 22nd hr), where the reference profile becomes a better representation. In other words, the max and min temperatures correspond to that of a hot design-day. The temperature profiles (depicted by the hot-day curves) shown in Figures 13-a,b,c,d resemble the flight data very closely.



(a) Post-flight Temperature Profiles for Sojourner Battery Packs



(b) Post-flight Comparison of Rover CPU and Power Board Temperatures



(c) Post-flight Comparison of Modem Temperature Profiles

Figure 12: Postflight (a) battery, (b) electronics boards and (c) modem temperature profiles.

MISSION THERMAL MANAGEMENT

UHF MODEM

The commercial UHF modem used for Rover-Lander communication developed difficulty early in the Rover mission. It was determined by the Telecom members of the Rover operations team that this was due to thermally-induced drift in the oscillation frequency of the transmit and receive crystals in the radio portion of the modems. Review of previous qualification data led to the determination that it was necessary to actively control the temperature of the Rover modem.

The interior of the Rover utilized a number of electrical resistive heaters mounted to the batteries and modem. The Rover computer contained software, which provided a thermostatic control function using a operator-settable set of PRT's for feedback. Furthermore, this sophisticated software also allowed the Rover to autonomously heat the modem for a specified length of time upon Rover wakeup or upon a failed transmission.

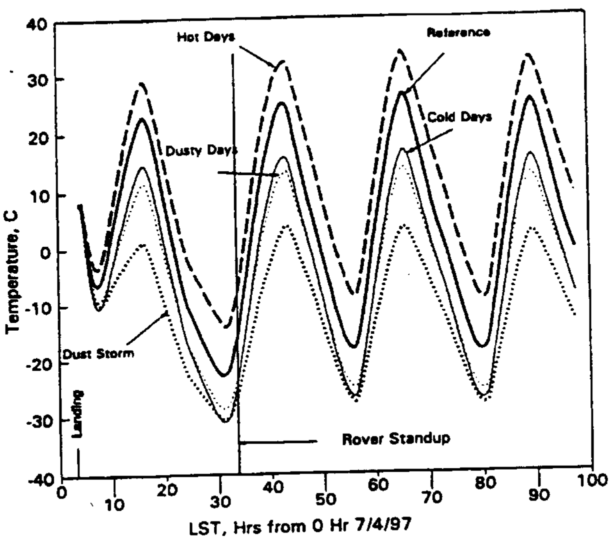
With wakeup temperatures of -35 to -25°C, the Rover would automatically heat the modem for a specified time each day utilizing early morning solar power. This heat would allow the Rover to dump its data acquired overnight (or late the previous sol after the Lander shutdown) to the Lander for downlink to Earth. After that, the normal internal dissipation of circuit boards kept the modem warm enough to allow an acceptably low bit error rate.

DAILY OPERATIONS

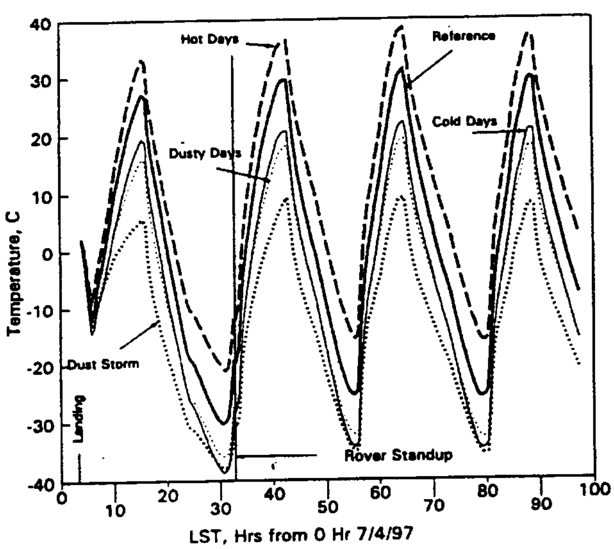
The process of managing the Rover's thermal status during the mission was governed by some simple rules. The only control of exterior components possible during the mission was the heating of drive and steering motors which was unnecessary as they were passively maintained within allowables. Interior thermal management rules were developed during the mission by the operations team in response to the UHF modem temperature sensitivity. The idea was to keep the modem warm while not overheating other interior electronics.

1. Wakeup Rover with 15 minutes of heating unless communication was to begin after 12:00 LST.
2. Set Modem to reheat on poor communications for 5 minutes as long as the modem temperature was less than 30°C.
3. Enable such heating only at times when the Lander is listening.

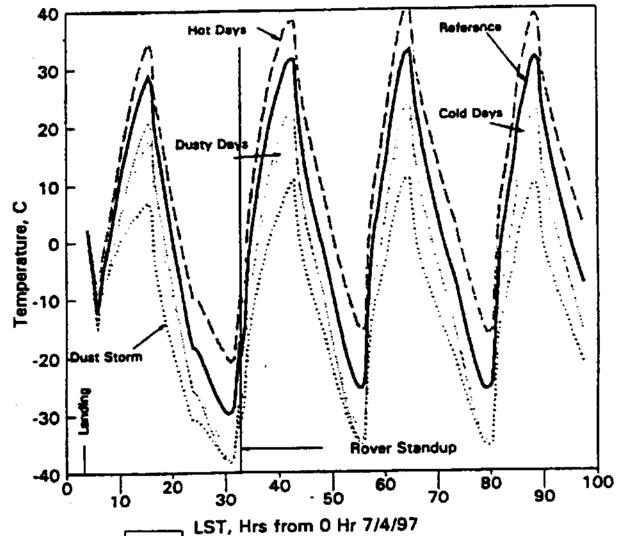
4. Perform normal heating (via solar-powered heaters mounted on the batteries, the largest thermal mass) to +30°C from 12:30 to 15:00 LST on days where Rover activity was low. This was to compensate for low sequenced power dissipation and to provide enough heat so as to maintain good temperatures by the next morning.
5. Limit the use of imaging after 13:00 LST so as to prevent overheating. This was because the transmission of Rover images to the Lander resulted in severe power dissipation for a prolonged period of time.



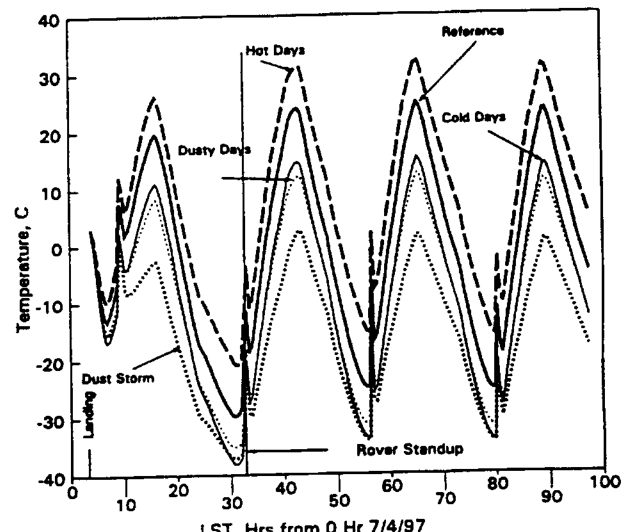
(a) Battery Temperature Sensitivities



(b). CPU Temperature Sensitivities



(c) Power Board Temperature Sensitivities



(d) Modem Temperature Sensitivities

Figure 13: Temperature sensitivities for (a) batteries, (b) CPU, (c) power board and (d) modem.

The daily sequence planners invoked these simple rules. The result was stable thermal performance where the computer boards were maintained between -20°C and +40°C each day with little variation despite the use of operational sequences that varied greatly from the pre-flight expectations.

CONCLUSION

The Sojourner Rover thermal design adequately protected the Rover during its mission on the surface of Mars. Simple operational control rules were used to supplement the design and allow for mission variations. Lessons learned from post-flight model correlation suggest some additional parameters should be used in the design of future surface vehicles and emphasize the value of pre-flight solar simulation testing.

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